INVESTIGATION OF TREATMENT PLANNING AND DOSE VERIFICATION PROCEDURES USING UNFLAT LINAC PHOTON BEAMS

A

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Introduction:

The medical electron linear accelerator (LINAC) is a device that uses high frequency microwaves to accelerate electrons generated by electron gun to high energies through an accelerator tube. These electrons are allowed to strike a high atomic number (Z) target for production of high energy x-rays. In general, such LINAC produce electron beams of energies between 4 to 25 Mega-electron Volts (MeV) and photon beams of nominal energies 6 Mega Volt (MV), 10 MV and 15 MV. This LINAC is used to treat varieties of cancer cases utilizing electron as well as photon beams. The conventional LINAC uses a conically shaped flattening filter (FF) made up of a high Z material in the photon beam delivery mode and acts as an attenuator, the beam hardener and the scatterer. It is located between the primary collimator and the monitor chamber and its main role is to compensate the non-uniformity of photon beam dose variation across the radiation field. However, it may not be necessary for the certain type of advanced radiotherapy treatments. The advanced beam therapy techniques such as stereotactic radiosurgery/radiotherapy (SRS/SRT) and stereotactic body radiotherapy (SBRT) where inhomogeneous dose distributions are applied and intensity modulated radiotherapy (IMRT) where varying fluence pattern across the beam are delivered, have stimulated the increasing interest in operating standard LINAC in a flattening filter free (FFF) mode [1].

A standard LINAC can therefore be used for generating photon beams either with flattening filter or without flattening filter [Figure 1]. Some of the disadvantages of flattening filter in a standard LINAC for advanced radiotherapy techniques are: 1) it acts as an attenuator and the beam hardener that result in the reduction of dose rate and hence increased beam delivery time,

2) relatively more head scattering increases leakage and out of field dose, and 3) homogeneous beam delivery and therefore a constant photon fluence pattern across the radiation field. A number of theoretical and experimental studies related to the clinical implementation of unflat photon beams demonstrated their suitability and superiority over flat photon beams [1-8]. In comparison to FF beam, the FFF beam results in significant increase in dose rate and dose per pulse and hence shorter dose delivery time, softening of X-ray spectrum and inhomogeneous dose across the field, reduction in the energy variation across the beam, decrease in head scattering, and hence reduces the leakage and out-of-field dose respectively [1-11]. The higher dose rates and therefore a shorter delivery time of FFF beam would keep the patient on the treatment couch for a shorter period of time. Thus, giving more comfort to the patient and decreasing the chances of intra-fractional setup inaccuracies [12]. These are critical elements in the techniques used for treatment of small lesion such as SRT, SBRT and SRS because of the usage of high fraction doses and of small margins for planned target volume (PTV), thus requiring very high accuracy and precision.

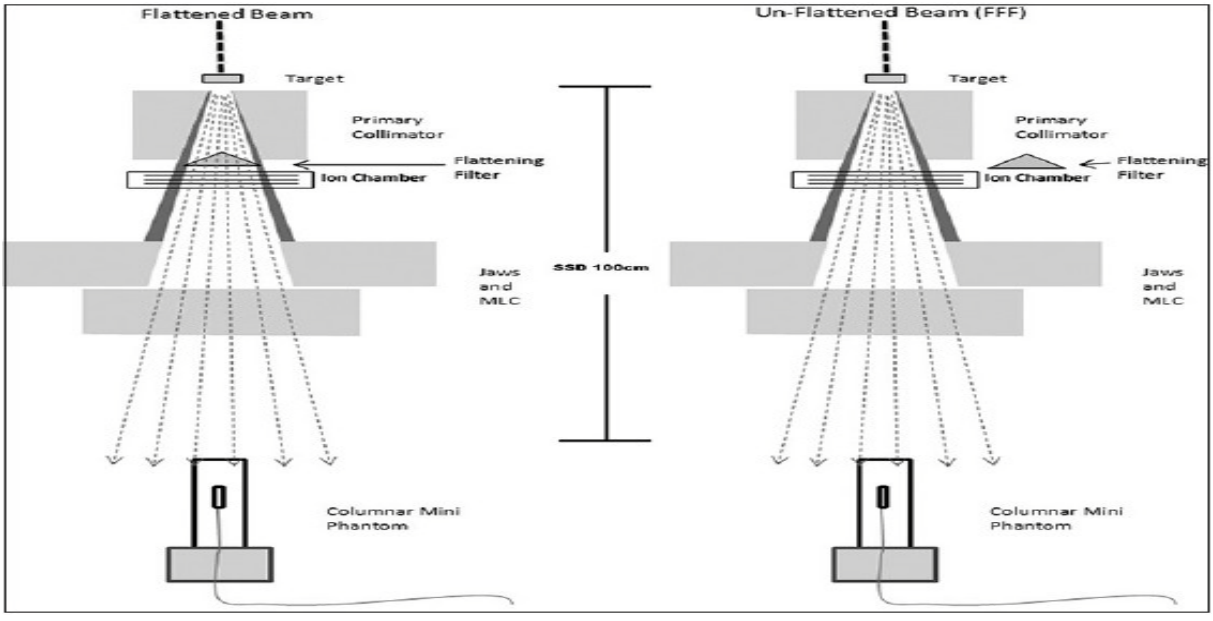

Figure 1: Schematic diagram of FF & FFF Photon Beam modes in LINAC

The certain studies concluded that the head scattering reduces to 1.5 %, compared to 8 % of the FF beam for the field sizes from 3x3 to 40x40 cm^2 [8]. The scattering reduction has a positive impact on lowering the risks of a secondary induced cancer for the treated patient [13]. Results also showed that FFF beam plan's delivery time was 2.5 times shorter than the FF beam [13]. For these reasons FFF beam treatment seems to be beneficial for small field treatment techniques such as SRT, SBRT and SRS which usage high fraction doses and of small margins for planned target volume (PTV). Thus, requiring higher dose rates and therefore a shorter delivery time.

Brief History of LINACs:

The history of the LINAC goes back further than its clinical implementation. The idea of LINAC was introduced by the Swedish physicist Ising in 1924. The concept of LINAC was first published in 1928 by Norwegian physicist Wideroe with paper titled 'About a new principle for producing higher voltages'. In 1952, Henry Kaplan and Edward Ginzton began building a medical linear accelerator. In 1956, the first medical linear accelerator in the Western Hemisphere has been installed at Stanford Hospital in San Francisco and the first patient a two year old boy with a retinoblastoma received radiation therapy. In 1962, Varian Company introduced the first isocentric 6 MV LINAC with a horizontal waveguide. Since the 1970s the LINAC had established itself and no further major changes have taken place in the concepts and constructions of LINAC. However, the development in improving its parts and adding more advanced features continued from then onwards to today's modern LINACs.

The FFs have been considered as an integral part of the treatment head of a LINAC for more than 50 years and reasons for the longstanding use are, however, historical ones [1]. In the 1991, O'Brien et al studied 6 MV FFF photon beams and main interest of the study was the need to reduce radiosurgery treatment delivery time [14]. Several other studies were performed after this and were mainly motivated with research interest in the characteristics of FFF beam [15-18]. In 2004, Fu et al investigated the effect of removing the flattening filter on reducing IMRT delivery time in a treatment planning study [19]. In 2006 onwards, MD Anderson and other groups began publishing. Their outcomes suggest that with a FFF accelerator better radiation treatments can be developed, with shorter treatment times and lesser doses to healthy tissues [1-11]. In 2010, Varian Medical Systems developed LINAC (TrueBeam) equipped with both FF and FFF photon beams and the product was made available for commercial uses from then onwards. At present, hundreds of medical linear accelerators with FFF features have been installed worldwide. Still the general guidelines regarding the acceptance, commissioning, quality assurance, planning and dose verification of FFF photon beam need to be compiled before it becomes a full replacement to the FF photon beam.

Literature Survey:

O'Brien et al. (1991) perceived the major drawback of doing stereotactic radiosurgery with a FF linear accelerator and that was long time required to deliver the target dose. Therefore, he attempted to decrease the treatment time for this technique by removing the flattening filter from an AECL Therac-6 linear accelerator and measured the characteristics of the resulting beam. Found that the flatness is acceptable for the field sizes used with this technique and the dose rate is increased by a factor of 2.75.

Fu et al. (2004) carried out a planning based study to Investigate the overall effect of FFF beam on the treatment delivery time of IMRT with MLCs implemented in the step and shoot method, as well as with compensators on six hybrid machines. The study showed that, the beam-on time reduces for both static MLC and compensator-based techniques. The relative IMRT treatment delivery time decreases more with lower dose rate, higher leaf speed and shorter verification and recording (V&R) overhead time.

Vassiliev et al. (2006) evaluated the dosimetric properties of 6 MV FFF and 18 MVFFF photon beams from a Varian Clinac 21EX accelerator, which comprises dose rate data, depth dose dependencies and lateral profiles in a water phantom, total scatter factors and transmission factors of a multileaf collimator. The FFF beams compare to FF beams have the higher dose rate by factors of 2.3 (6 MV) and 5.5 (18 MV) on the central axis; lower out-of-field dose due to reduced head scatter and softer spectra; less variation of the total scatter factor with field size; and less variation of the shape of lateral dose profiles with depth. The findings suggest that with a flattening filter free accelerator better radiation treatments can be developed, with shorter delivery times and lower doses to normal tissues and organs.

Parsai et al. (2007) hypothesized that IMRT treatments may be carried out after the removal of FF component from LINAC in spite of the criticality to standard treatments. They performed measurements using a scanning water phantom after the FF had been removed from Elekta SL-25 LINAC and found that Monte-Carlo simulated as well as measured beam profiles showed an increased dose on the central axis. The Monte Carlo simulations showed increase by a factor of 2.35 for 6 MV and 4.18 for 10 MV beams. In conclusion the study expected a shorter treatment time and a more accurate dose delivery to the target

due to greater photon fluence and reduction in dose outside of the treatment field respectively.

Cashmore et al. (2008) studied the effects arises on the operation and beam characterization of LINAC after the removal of FF. Dosimetric benefits are reported here which include a reduction in head scatter by approx. 70%, decreased penumbra (0.5 mm), lower dose outside of the field edge (11%) and a doubling in dose rate (2.3 times for open and 1.9 times for wedged fields). The greatest benefit of FFF use is perceived to be for IMRT where increased dose rate combined with reduced head scatter and leakage radiation should lead to improved dose calculation, giving simpler, faster and more accurate dose delivery with reduced dose to normal tissues.

Kragl et al. (2009) examined dosimetric data from three different beam qualities provided by Elekta Precise LINACs, operated with and without flattening filter. Depths of dose maxima for FF and FFF beams did not deviate by more than 2mm and penumbral widths agreed within 1mm. In FFF mode the collimator exchange effect was found to be on average 0.3% for rectangular fields. Between maximum and minimum field size head scatter factors of FFF beams showed on average 40% and 56% less variation for 6 and 10MV beams than conventional beams. They found the phantom scatter factors for FFF beams differed up to 4% from the published reference data and suggested the reference data need to be reconsidered for medical accelerators operated without a flattening filter.

Dalaryd et al. (2010) A Monte Carlo model of an Elekta Precise linear accelerator has been built and verified by measured data for a 6 and 10 MV photon beam running with and without a FF in the beam line. In this study the flattening filter was replaced with a 6 mm thick copper plate, provided by the

LINAC vendor, in order to stabilize the beam. The investigated characteristics of this new beam included output, spectra, mean energy, half value layer and the origin of scattered photons. The results showed an increased dose output per initial electron at the central axis, reduction in the number of scattered photons from the accelerator head and softening of photon energy spectrum of the FFF beam compared to a FF beam.

Wang et al. (2011) investigated the entrance dose of FFF photons in the buildup region and compared it with that of conventional flattened photons. The FFF photons have a higher entrance dose than that of the corresponding flattened photons for field size smaller than 10x10 cm^2. However, the difference is not substantial and may be clinically insignificant.

Georg et al. (2011) described the treatment head physics of FFF beams, their characteristics and the resulting potential advantages in their medical use. The dosimetric characteristics of FFF beams have an effect on treatment delivery, patient comfort, dose calculation accuracy, beam matching, absorbed dose determination, treatment planning, machine specific quality assurance, imaging, and radiation protection. Due to the convincing arguments of removing the FF, it is expected that more vendors will offer dedicated treatment units for advanced photon beam therapy in the near future. Several aspects related to standardization, dosimetry, treatment planning, and optimization need to be addressed in more detail in order to facilitate the clinical implementation of unflattened beams.

Sharma et al. (2011) reviewed the number of advantages of using a FFF beam especially for advanced radiotherapy techniques and pointed out few limitations such as using relatively higher energy photon beam for SRT, limited speed of current Multi Leaf Collimators (MLCs), and off-axis distance-dependent

modulation in IMRT. He also discussed the future challenges such as criteria for beam quality evaluation and penumbra, establishment of dosimetry methods, and consequences of photon target burn-up, which need to be addressed for establishing this beam as an alternate to the FF beam.

Huang et al. (2012) reported the characteristics of an equivalent quality unflattened (eqUF) photon beam in clinical implementation and provided a generalized method to describe FFF photon beam profiles. The analysis shows that the percent depth dose beyond dmax was very similar to that of the FF-beam; surface dose and out-of-field dose were lower; penumbra was slightly wider; variation in head scatter and phantom scatter with changes in field size was smaller; the variation in the profile shape with change in depth was also smaller. The eqUF beam is stable 0.072 s after the beam is turned on, and the five-year beam stability was comparable to that of the FF photon beam.

Fogliata et al. (2012) proposed the definitions and suggestions for some dosimetric parameters for use in quality assurance of FFF beams generated by medical LINACs in radiotherapy. By following the recommendations of this report we foresee that the introduction of FFF beams into the clinic will be as safe for the patient as other radiotherapy procedures existing in the radiation oncology community today.

Wuerfel et al. (2013) demonstrated that the small field dosimetry poses new challenges for medical physicists. Therefore, the positional accuracy is very important, the volume effect should be excluded as much as possible and some of the common measurement methods, e.g., where to put the reference detector in scanning measurements, have to be reconsidered. Reference dose and output factors can be measured by cross calibration in field sizes of the order of 4 cm x 4 cm to 5 cm x 5 cm.

Sahani et al. (2014) recommended the beam characteristics evaluation criteria for the clinical acceptance of FFF photon beam as these parameters are not yet available for such photon beams. The recommendations included the evaluation of quality index, degree of unflatness, difference in percentage surface dose between flat and unflat photon beams, percentage depth dose at 10 cm depth, off-axis-ratios and radiation beam penumbra. Recommendations were also made for periodic quality control check of the unflat photon beams and constancy evaluation in the beam characteristics.

Xiao et al. (2015) showed that the removal of the flattening filter increases beam intensity, especially near the central axis. Increased intensity reduces treatment time, especially for high-dose SRT and SRS. Furthermore, removing the flattening filter reduces out-of-field dose and improves beam modelling accuracy. FFF beams are advantageous for small field (e.g., SRS) treatments and are appropriate for IMRT. Several areas still warrant further research and development.

Masanga et al. (2016) determined the appropriate detectors for output factor measurement of small fields in 6 and 10 MV flattening filter free photon beams using five different detectors. Field sizes were varied between 0.6 × 0.6 and 4.0 × 4.0 cm^2. For the smallest field size, the variations of output factors compared among the detectors were 13%. The output factor measured using Exradin A16 ionization chamber had the lowest value and increases in sequence with CC01ionization chamber, microdiamond (diamond dosimeter), microLion (liquid ionization chamber) and EDGE detectors, respectively, for both 6 and 10 MV photon beams. They concluded that, IBACC01, Exradin A16, microLion, microDiamond and EDGE detectors seem to be the detectors of choices for small field output factor measurement of FFF beams down to 1.6×1.6 cm^2.

Dang et al. (2017) Analysed and compared the plan quality and treatment time between FF and FFF beam to assess the efficacy of FFF beam for SBRT. They reviewed several papers meeting their three criteria; radiation therapy, FFF and treatment delivery from year 2010 to 2015. Plan quality was evaluated using conformity index (CI), heterogeneity index (HI) and gradient index (GI). The beam-on-time (BOT) with FFF is substantially reduced, and appears to impact the frequency of intra-fraction imaging which, in turn, affects total treatment time. Based on planning tumour volume (PTV) coverage, dose to OAR and healthy tissue sparing, FFF beam is clinically effective for the treatment of cancer patients using SBRT. They recommended the use of FFF beam for SBRT based on these factors and the reported overall treatment time reduction.

Prez et al. (2018) addressed the question to which extent k_Q factors, based on a $TPR_{20,10}$ codes of practice (CoP), can be applied in clinical reference dosimetry. The study was done with a transportable water calorimeter. Based on the measurements made with the equipment described in this study the authors conclude that the k_Q factors provided by the NCS-18 and IAEA TRS-398 codes of practice can be applied for flattening filter free beams without additional correction. However, existing codes of practice cannot be applied ignoring the significant volume averaging effect of the FFF beams over the ion chamber cavity. For this a corresponding volume averaging correction must be applied.

Research Issues/gaps:

The flattening filter free beam mode is a relatively new technology, so there are still some uncertainties that need to be clarified before it becomes a full replacement to the flattened beam option. Some of the research gaps such as, one aspect that needs to be dealt with are to set new technical criteria, standards

and definitions regarding the FFF beam, similar as they exist for the conventional beam [1, 8]. Some of them include the initial acceptance measurements, and the periodic quality assurance which can be performed in daily, monthly or even yearly bases. The application of FFF beam requires further development of the today's MLC technology because for many optimized segments in static IMRT the travelling time of the leaf is too long and for dynamic and rotational IMRT, the speed of the leaf collimators is slower than required [8]. Moreover, the limitation is more evident for large treatment fields. When such fields are in use, MLCs are used to regulate the central high intensity of the beam, for example supplying a more uniformed dose within the large planning target volume (PTV). Consequently, larger and faster MLCs are needed. Providing beam uniformity would also lead to a reduction in the initial dose rate, which actually was one of the main advantages of the FFF beam [10]. This means that FFF beam delivery is more efficient in lesions of relatively small size [11]. More information is needed when it comes to the immediate and long term bio-logical effects of the very high dose rates on the healthy tissues and the ones inside the target volume [9, 10]. In addition, all dosimetric properties and beam modeling, beam data acquisition and absolute dosimetry of the beam have to be carefully studied especially when it comes to small field applications [10]. Lastly, some other uncertainties that need to be clarified are related to the higher dose rates and the performance of the radiation detectors, starting from the ion chambers to the portal imaging devices.

Problem Formulation:

A number of theoretical and experimental studies were reported in past dealing with beam characteristics, dosimetric properties, and radiation safety aspects on existing standard LINACs by removing the flattening filter to generate FFF photon beam [1-5]. Studies related to the clinical implementation of unflat

photon beams demonstrated their suitability and superiority over flat photon beams [1-7]. The dosimeric parameters described in the AAPM (American Association of Physicist) TG (Task Group) 142 and TRS (Technical Series Report) 398 e.g. field size, depth dose, Beam quality, and flatness, symmetry, penumbra and peripheral dose, are very well studied and standardized for FF photon beam. The FFF photon beam being the latest technology, although the studied related to its beam characteristics has been carried out by many groups and reported as well, the standardization of beam parameters of unflat photon beam are still under investigation phase. The radiation beam properties such as Beam quality definition, depth dose analysis, surface dose, flatness, symmetry and penumbra, need to be addressed for establishing this beam as an alternate to the FF beam. The FFF photon beam delivery is more efficient in lesions of relatively small size [11]. The dosimetry of small fields remains a challenging topic and difficult to achieve with accurate measurements because of loss of charged particle equilibrium, source occlusion and finite size of detectors [24].

The first problem of my study is on small field dosimetry of FFF beams using different types of detectors such as ionization chambers of different volumes, thermoluminescent dosimeter (TLD), radiochromic film, diodes, etc. It can be helpful in concluding what detectors are relatively more suitable over others for such studies. It will be also help to describe how & why they are superior and what are the merits and demerits of the dosimeters. The second problem of my study is related with the various treatment planning procedures adopted for finalizing a treatment plan of cancer patients of different categories such as H&N, Thorax and Abdomen etc using FFF photon beam. It will provide a meaningful data to conclude which planning techniques such as 3-dimensional conformal radiotherapy (3DCRT), IMRT and Rapid Arc are relatively more superior over others. It will also give a better idea about what treatment procedure to be best adopted for finalizing a treatment plan of cancer patients of

different categories such as Head &Neck (H&N), Thorax and Abdomen etc. The last problem of my study is related with the verification of actual radiation dose delivery of Flattening filter free (FFF) photon beam by incorporating different Dosimetry systems. This will be very important problem as it is related with actual dose delivery to cancer patients and its verification with treatment planning system (TPS) calculated value and the dosimetric measured value. Therefore, the dosimetric system used for such an important measurement need to be compared for their relative suitability and superiority for the verification of doses of different types of treatment plan. It will be helpful to describe how & why they are superior over others and what are the merits and demerits of the dosimetric system used for verification of radiation dose delivery of FFF beam.

Objectives:

1. Comparative study of beam profile and output doses of small Unflat LINAC photon beams using ionization chambers, TLD, Diode detector and Radiochromic film for selection of appropriate detector for dosimetry.
2. Comparative study of 3D-CRT, IMRT and VMAT planning procedures adopted for Head and Neck, Thorax and abdomen cancer patients using Acuros and AAA algorithm based dose calculation.
3. To verify the radiation dose delivery of Unflat photon beam using Map check, Arc check and Portal dosimetry systems.

Contribution and need of the proposed Research:

The outcome of these studies will give some insight about the selection of appropriate detector to be used for dosimetry of small FFF photon field, the optimized method of the treatment planning of a cancer case and appropriateness of dose verification procedures in FFF photon beam. The need of the proposed work is because of FFF photon beam is a relatively new technology for the treatment of different categories of cancer cases, so there are still some uncertainties in measuring, planning and verification of FFF radiation doses and therefore these issues need to be clarified before it becomes a full replacement to the FF photon beam.

Methodology/ Planning of work:

In this study, the radiation dosimetry and quality assurance of Medical Linear Accelerator will be performed with the help of the dosimetry system. The protocols to be used for radiation beam data collection and testing as accordance with the recommendation of international practice and guidelines such as AAPM TG142 & 106 reports, TRS 398 and AERB (Atomic energy regulatory board, INDIA) guidelines. The ionization chambers, radiation field analyser and water phantom will be used for beam data collection and dosimetric measurements. Beam data measurement will be performed for photon energies of 6 MV, 10 MV flattening filter beam and 6 MVFFF, 10 MVFFF flattening filter free beams. For dosimetry (output/output factor/beam profile/surface dose, etc) of small FFF beam different types of detectors such as ionization chambers of different volumes, TLD, radiochromic film, diodes, etc will be used in this study. In the small field dosimetry acquisition sampling time will be increased to improve the signal to noise ratio and also data to be taken without reference detector to avoid shadow from the reference detector. Beam quality will be

measured for the nominal beam energy along with measured TPR20/10 values for 10 cm × 10 cm collimator setting and to be recorded for all available FFF photon beam energies. Surface doses will be measured for field sizes 1 × 1cm^2 to 6 × 6 cm^2, Field width and penumbra will be analyzed for field sizes 1 × 1cm^2 to 6 × 6 cm^2 and compared with the corresponding nominal flattened photon beam energy. The dosimetric parameters such as field size, flatness, symmetry, and penumbra to be measured and evaluated following the methods applied for flattened photon beams as recommended by International Electrotechnical Commission (IEC 60976, 2008). The off‐axis ratio at ± 3 cm lateral distance from central axis at 10 cm depth for 10 cm × 10 cm collimator setting will be measured for all the available unflattened photon beam energies.

Depth dose profiles for1 × 1 cm^2 to 6 × 6 cm^2 collimator setting will be measured. The depth of maximum dose (dmax) and percentage depth dose (PDD) at 10 cm depth will be measured for all the available unflattened photon beam energies. Beam profiles for 1 × 1cm^2 to 6 × 6 cm^2 collimator setting at 10 cm depth in isocentric setup (SAD) for all the available unflattened photon beam energies to be measured and the profiles will be analyzed to evaluate the Field size, symmetry and degree of unflatness. The field size(s) will be defined by collimator settings only. For verifying the constancy of the beam profiles along major axes (cross‐plane and in‐plane), the separation between inflection points (IPs) will be recorded. Inflection point will be identified as per its mathematical definition. However, for practical purposes, it can be approximated as the mid‐point on either side of the high gradient region (sharply descending part) of the beam profile. Its location can be identified as follows [Figure 2a]: Locate starting point (S) and end point (E) of high gradient region of the beam profile. The vertical separation between S and E is the height (h) of the high gradient region of the beam profile. Inflection point is located at h/2 on the beam profile from either location (S or E). Symmetry will be

evaluated following the methods recommended for flattened photon beams by International Electrotechnical Commission (IEC 60976, 2008). To measure the degree of unflatness, the lateral distance from the central axis at 90%, 75% and 60% dose points on either side of the beam profile will be recorded along major axes for all the available FFF photon beam energies [Figure 2b]. For determining radiation beam penumbra, dose value at IP will be taken as reference dose value (RDV). Points P_a and P_b, which are located at 1.6 and 0.4 times of RDV, respectively, to be, identified [Figure 2a]. Lateral separation between P_a and P_b on either side of the profile will be the measure of the radiation beam penumbra.

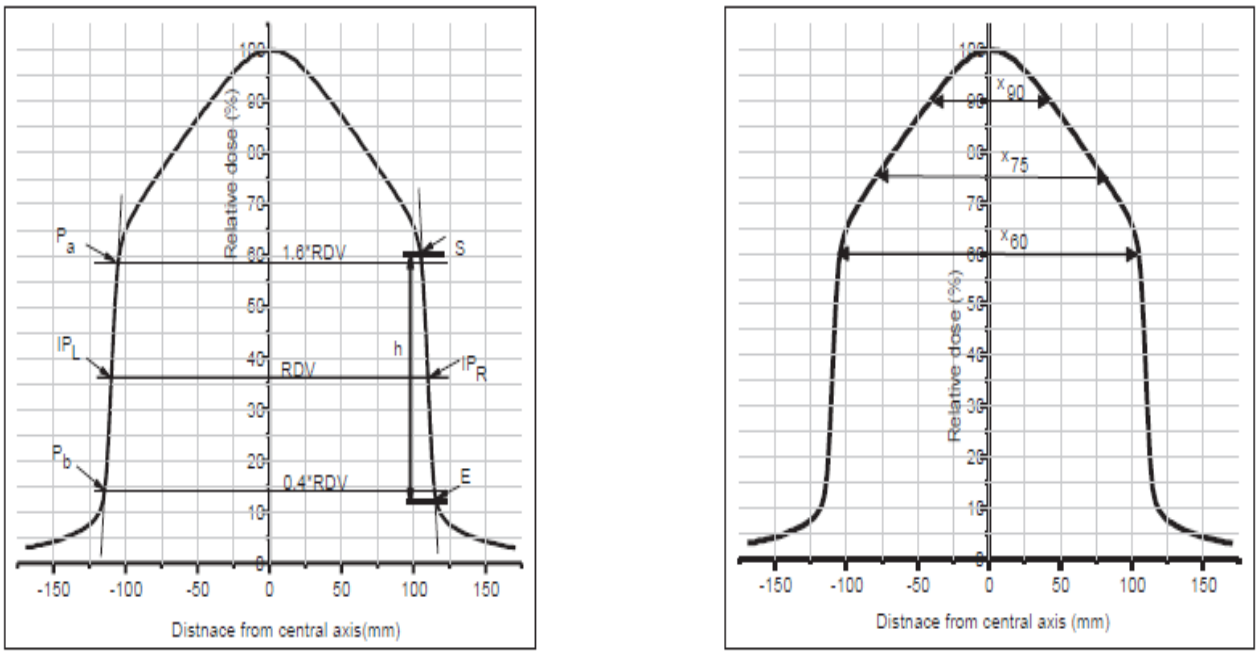

Figure 2: Schematic Diagrams for determining a) inflection point and penumbra and b) degree of unflatness.

The Eclipse Treatment Planning System (TPS) will be used to study the various treatment planning techniques adopted for finalizing a treatment plan of cancer patients. The technique adopted for treatment plan of different categories such as H&N, Thorax and Abdomen etc will be analysed and compared. The

different algorithms such as Acuros XB, Anisotropic analytical algorithm (AAA) and Monte Carlo Method etc will be used for radiation dose calculations of treatment plan. The relative suitability and superiority of different algorithms will also be analysed.

The dosimetry system such as Map Check array, Arc Check array, Portal imager and films will be used for the verification of radiation dose delivery of Flattening filter free (FFF) photon beam. 3-DVH (Dose Volume Histogram) software will be used for analysis of measured delivery radiation doses across the beam by Map check and Arc check dosimetry system. The Portal dosimetry software will be used to analyze the doses obtained from portal imager. The Sun Nuclear Corporation (SNC) advanced IMRT film verification software will be used for the analysis of doses measured from films.

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Place of Work:

The place of work for the study will be as follows;

1. Radiation Physics Laboratory, Department of Applied Physics, Giani Zail Singh Campus College of Engineering and Technology, MRSPTU, Bathinda under the supervision of Prof. (Dr.) Sandeep Kansal, Professor & Head of the department.
2. Department of Radiotherapy, Government Medical College (GMC) Patiala under the supervision of Co-Supervisor Dr. V.K. Dangwal, Associate Professor (Medical Physics).

Resources required & availability status:

1. Medical Linear Accelerator (available at GMC Patiala)
2. Dosimetry Systems such as Radiation Field analyzer (RFA), Water Phantom, Ion chambers, diode detectors, TLDs and Films etc and software for analysis of radiation doses. (Available at GMC Patiala).
3. Treatment planning system (TPS) equipped with algorithms such as Acuros XB, Anisotropic analytical algorithm (AAA) and Monte Carlo Method etc for radiation dose calculation (Available at GMC Patiala).
4. The dosimetry system such as Map Check array, Arc Check array, Portal imager and films for the verification of delivery radiation doses and verification software for analysis of calculated and measured doses (Available at GMC Patiala).